Blooms of σ^0 in the TOPEX Radar Altimeter Data

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ABSTRACT

Data from satellite altimeters are often degraded by the occurrence of unrealistically high radar return cross sections, which indicate a breakdown of the rough surface scattering model used to interpret these measurements in terms of satellite to sea surface height ranges. The TOPEX altimetric data are examined and nearly 200 000 such events during the 7-yr period, 1993–99, inclusive, are identified. The primary purpose of this paper is to make a comprehensive description of where and when these events occur, which is important because many of the communities that make use of the TOPEX data are generally unaware of this phenomenon. It is shown that these events affect almost 6% of the over-ocean TOPEX data, but only approximately 60% of these events are rejected by the recommended TOPEX data flagging. A global description of these events is made, showing that the events are associated with regions of climatologically weak winds (e.g., the summer hemispheres and the western Pacific warm pool region), supporting the existing hypothesis that these events are due to returns from surfaces where centimeter-scale waves are suppressed. The TOPEX results are confirmed with a comparison to anomalous returns from the NASA Scatterometer (NSCAT), and the relationship to very low wind speeds is further examined using the Tropical Ocean Global Atmosphere–Tropical Atmosphere Ocean array (TOGA–TAO) moored buoys. Finally, it is shown that there is some evidence that not all of the events can be accounted for by very low wind speeds. This suggests that future work might exploit the occurrence of these events to study other phenomena, such as surface slicks, that may lead to additional geophysical applications of the altimetric data.

1. Introduction

During the decade since the launch of the TOPEX/Poseidon radar altimetry mission in 1992, satellite altimetric estimates of sea surface height have become a commonly used dataset by many geophysicists, including oceanographers, geodesists, and solid earth physicists. The wide use made of these data is clearly demonstrated in the recent book edited by Fu and Cazenave (2001), for example, and the interested reader is referred to that text for additional information about the applications of satellite altimetry. For our present purposes, however, we simply note that satellite altimeters measure the height of the sea surface by differencing a precise determination of the satellite height, which is derived from independent tracking data, with an estimate of the satellite to sea surface range, which is measured by the radar altimeter. Precise determination of these range values is thus critical to the success of the satellite altimetric method of determining sea surface height variability.

In addition to their range estimates, though, Topography Experiment for Ocean Circulation (TOPEX), which is the National Aeronautics and Space Administration (NASA) altimeter on board the TOPEX/Poseidon satellite, and similar over-ocean satellite-borne radar altimeters also produce estimates of the ocean surface's radar backscattering cross section at normal incidence. This cross section is usually designated by $\sigma^0(0)$, but we will simplify this in the following to σ^0. In this paper we are concerned with possible contamination of altimeter data by what we term "σ^0 blooms," by which we mean regions of over-ocean altimeter data characterized by unusually high σ^0 values. Of course, high backscatter is expected under low wind conditions, so a correspondence of high σ^0 values with low wind speeds is expected. We need to emphasize, however, that these high σ^0 values also signal a breakdown in the basic assumptions used in estimating sea surface height from radar returns, and thus a closer examination of these events has significance beyond the connection to low wind speeds.

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A detailed discussion of the inner workings of the radar altimetry system is beyond the scope of this paper, but we will provide a brief review for the reader unfamiliar with these details. For readers interested in further details, the recent review by Chelton et al. (2001) provides a good starting point. Also, Zieger et al. (1991) have summarized the TOPEX radar altimeter's range tracking and significant wave height estimation using a radar altimeter mean return waveform model. The waveform model development starts from Moore and Williams (1957), who showed that the mean radar power return for incoherent scattering from a rough surface for near-normal-incidence scattering could be expressed as the convolution of 1) the transmitted pulse shape and 2) a term that included effects of antenna pattern, pointing angle, surface properties, and distance. Starting with the convolution model, Brown (1977) used assumptions common to satellite radar altimetry and produced a simplified closed-form expression for the flat-sea impulse response. Later, Rodriguez (1988) pointed out the importance of correcting the Brown flat-surface result to account for the finite radius of the earth, as further discussed in appendix A of Chelton et al. (1989).

All satellite radar altimeters assume the validity of this mean return waveform model, which is in turn based on the assumption of incoherent radar scattering from a rough surface. An example is shown in Fig. 1. The power return estimates under normal conditions are shown as open diamonds, and the fitted waveform model is shown as a solid line. The mean return waveform fit rises to a peak value, which is used to make the σ^0 estimate, and then diminishes (''plateau decay'') at a rate that is a function of the beamwidth and the attitude angle. For any specific beamwidth the fastest possible plateau-relative decay rate occurs for nadir pointing, which has a pure exponential decay after its peak. As the attitude angle is increased from zero, the plateau will decay less rapidly relative to the peak and the decay will no longer be purely exponential. The rate of waveform plateau decay is used to estimate the attitude angle in radar altimeters such as *Seasat*, *Geosat*, and TOPEX. If the waveform estimates in the plateau region decay too rapidly, as is the case during the σ^0 bloom event shown in Fig. 1 (star symbols), most altimetric data processing systems will set an attitude estimation error flag. Since TOPEX has an extremely good attitude control system the true attitude value will never exceed 0.5°, and an estimate greater than this is therefore interpreted as a bad-attitude indicator rather than a meaningful value. That is, the too-rapid plateau decay of Ku-band altimeter waveforms in σ^0 bloom regions is an indication of a partial breakdown of the incoherent scattering model. As the radar altimeter moves into σ^0 bloom regions there is not an easily characterized waveform shape change; we can only report that many, but not all, of the return waveforms in such regions will have the too-rapid plateau decay.

To make our discussion more specific to the TOPEX altimeter, Fig. 2 shows the Ku-band σ^0 values for several data segments during a typical TOPEX 10-day data cycle. The peaks seen in this figure are what we refer to as σ^0 blooms and are characterized by sharp increases of σ^0, on the order of 10 dB, above the surrounding data. Also, most of the apparent blooms exceed 14 dB, which generally indicates invalid data. Of course, most users of altimetry are primarily interested in the final sea surface height estimates. In the summary section below, after we have defined how we selected bloom events, we will present a brief analysis of the effect on the heights. These effects are subtle and will not trouble most users, but do include a small bias error that may affect the most demanding applications of the sea surface height data. The σ^0 blooms persist for several tens of seconds or more, and it is not difficult to identify such blooms in any sufficiently long segment of the TOPEX data. In the figure we also indicate locations where the satellite attitude exceeds 0.6°, which is another indicator of unrealistic data, as discussed above. We have found that excessively high σ^0 estimates in TOPEX bloom regions are invariably accompanied by at least some of the attitude values being flagged. This plot is not atypical, in that there is about a 20% probability that at least one σ^0 bloom will be obvious in any 1250-s segment of over-ocean TOPEX data, such as those shown here. That is, as we will detail below, σ^0 blooms exist in more than 5% of all TOPEX over-ocean data.

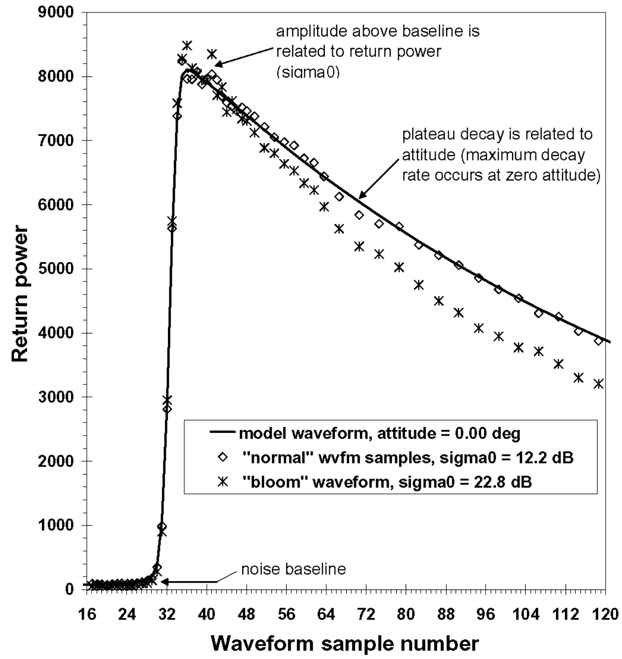

FIG. 1. Illustration of TOPEX Ku-band rescaled waveform observations and model (1-s data averages). The open diamonds show observed power return as a function of waveform sample, which can be considered a time delay. The solid line shows the fit to these samples from the rough surface scattering model discussed in the text. The σ^0 value is proportional to the peak value, while the satellite attitude is proportional to the rate of decay after the time of peak return. The example shown is for a nadir return where the rate of decay is the maximum allowed by the model. The star symbols show the return vs time delay for a sample within a σ^0 bloom region. Note that the fitted σ^0 value is higher and the rate of decay is faster than is theoretically possible from a rough surface.